From Knowledge to Power

The Comprehensive Handbook for Climate Science and Advocacy

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From Knowledge to Power: The Comprehensive Handbook for Climate Science and Advocacy

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Chapter 1

Earth's Climate System

From the indigenous North American people, who first learned how to live in harmony with our land, to naturalists, poets, and politicians—like John Muir, Walt Whitman and Al Gore—[1] Americans have been blessed to have many eloquent voices speaking on the importance of environmental stewardship. Most scientists came later to this calling, but moved by the climate crisis, are overcoming natural reticence and recognizing that their advocacy adds a crucial dimension to the conversation.[2] We should listen closely to all these voices with both our heads and our hearts. In today's America, though, it is the hard-headed, no-nonsense voice of science, now under sustained attack by those who find its truths *inconvenient*, that most needs to be amplified.[3]

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1 For perspectives on Native American Nature writing, see Lee Schweninger, "Writing Nature: Silko and Native Americans as Nature Writers," *Multi-ethnic Literature of the United States*, Vol. 18 (1993):, 47-60, https://doi.org/10.2307/467933 For an anthology of American nature writing since Thoreau, see Bill McKibben, ed., *American Earth* (New York: Literary Classics of the United States, 2008).

2 Julia Rosen, "Climate Change Fears Propel Scientists Out of the Lab and Into the World," *Los Angeles Times*, December 17, 2019, https://www.latimes.com/environment/story/2019-12-17/scientists-become-advocates-on-climate-change.

3 This invokes Al Gore's classic *An Inconvenient Truth*. Al Gore, *An Inconvenient Truth* (New York: Rodale, 2006). For books describing attacks on the credibility of climate science and scientists, see Michael Mann, *The hockey stick and the climate wars. Dispatches From the Front Lines*. (New York: Columbia University Press, 2012) and Naomi Oreskes and Eric Conway, *Merchants of Doubt* (New York: Bloomsbury Press, 2010).

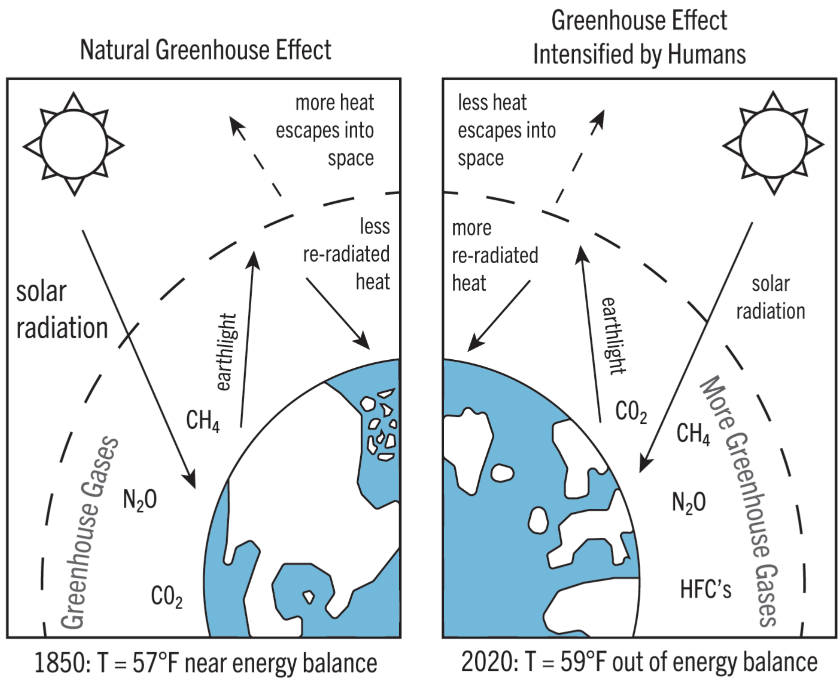


Figure 1.2: Natural (left) and human-enhanced (right) greenhouse effect. Compared to 1850, the amount of absorbed and reradiated Earthlight has increased, while the amount of heat escaping to space has decreased. Based on Figure 33.1 of the US National Climate Assessment, see https://nca2014.globalchange.gov/report/appendices/climate-science-supplement.

We have just learned that the 70 percent of the Earth system that absorbs sunlight warms up as a result. That extra heat is transferred throughout the surface and atmosphere (for example, by winds and ocean currents), so the parts of Earth that reflected sunlight warm as well. But notice next that the sunlight, of course, keeps on coming in. Something else must be at work, or else Earth would continue to warm and warm, and indeed would have disintegrated a long time ago. To prevent this, much of the absorbed sunlight is re-emitted back out into space. We can clearly see this phenomenon, using a specialized camera on an orbiting satellite. The Earth is actually glowing: it is emitting radiation (Earthlight) just like the Sun (Figure 2)![16] The big difference here is that the Earth, being much cooler than the Sun, emits much lower energy radiation, called *infrared radiation*, which is too weak to see with the unaided eye. You can, however, feel this exact type of radiation by standing under a heat lamp.

16 See https://www.wunderground.com/maps/satellite/regional-infrared for examples of IR images.

Box 1.3: Counting Carbon

Just as Americans use a different temperature unit, we also use different length units, mass units, and volume units. One mile is a little over 1.6 kilometers, for example, and one inch is 2.54 centimeters.

To count carbon as scientists do, it helps to be comfortable with the scientific notation for powers of ten. 100 (10 x 10) is written as 102, and 1000 (10 x 10 x 10) is 103. When you multiply the numbers, add the exponents: 100 x 1000 is 102 x 103, or 105. So there are 105 centimeters in one kilometer.

Carbon counting is done in units of mass. One American pound equals 453 grams, the scientific unit for mass. There are 1000 grams in 1 kilogram, so one pound equals 0.453 kilograms. Looking at it the other way, there are 2.2 pounds in one kilogram (kilo).

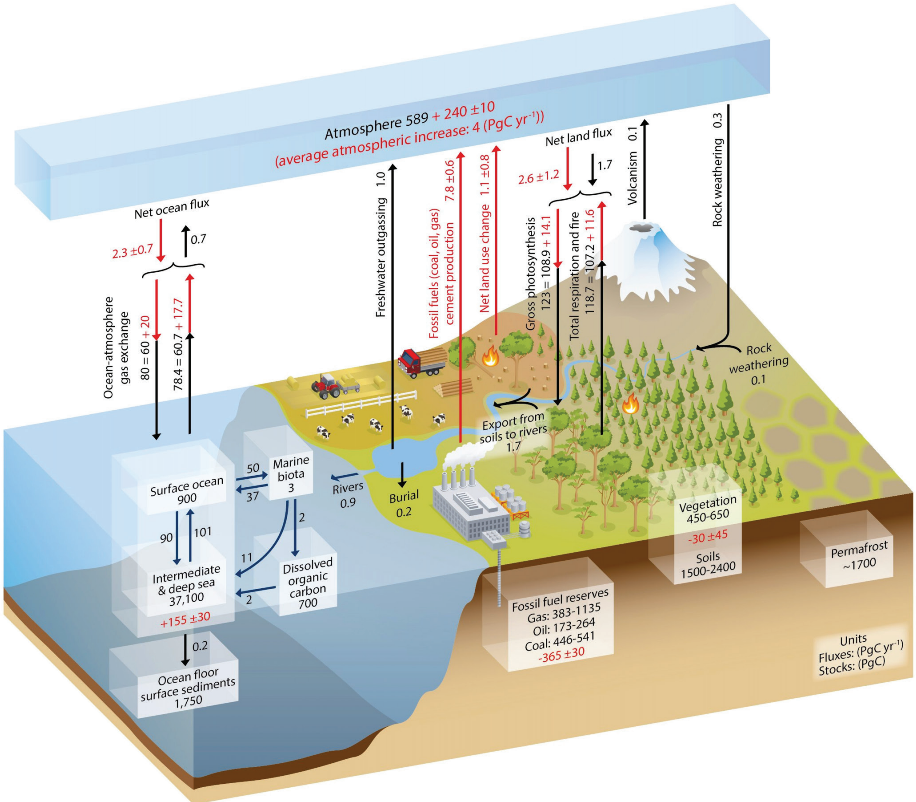
Scientists often report amounts of carbon dioxide in the atmosphere, but other times they report only the mass of the carbon part of the molecule, ignoring the two oxygens. Fortunately, going between these is not difficult. A carbon dioxide molecule is made of one carbon atom joined to two oxygen atoms (Figure 3). Chemists tell us that oxygen atoms are one and one-third times heavier than carbon atoms, or 4/3. So, if a carbon atom weighs one unit, or 3/3, then a carbon dioxide (CO_2) molecule weighs 3/3 + 4/3 + 4/3 = 11/3.

If you are looking at data reporting the mass of carbon in the atmosphere, multiply by 11/3 (the ratio of carbon dioxide mass to carbon mass) and you will have the mass of carbon dioxide. Similarly, you can multiply the mass of carbon dioxide by 3/11 to get the mass of the carbon part of the molecule.

The most common units in carbon counting are megatons and gigatons. In the metric system, one ton is 1000 kilograms, or 106 grams. So, one megaton, abbreviated Mt, is one million (106) metric tons, and one gigaton, abbreviated Gt, is one billion (109) metric tons.

It is also easy to convert ppm concentrations into masses. Emitting about 7.3 Gt of CO_2 to the atmosphere increases its concentration by 1 ppm, and about half of that would be taken up by the land and oceans, in the "fast" carbon cycle (see the text).

industrial agriculture—brought about by human activities. It is important to distinguish this from the *natural greenhouse effect* described above (compare the left and right panels in Figure 2).

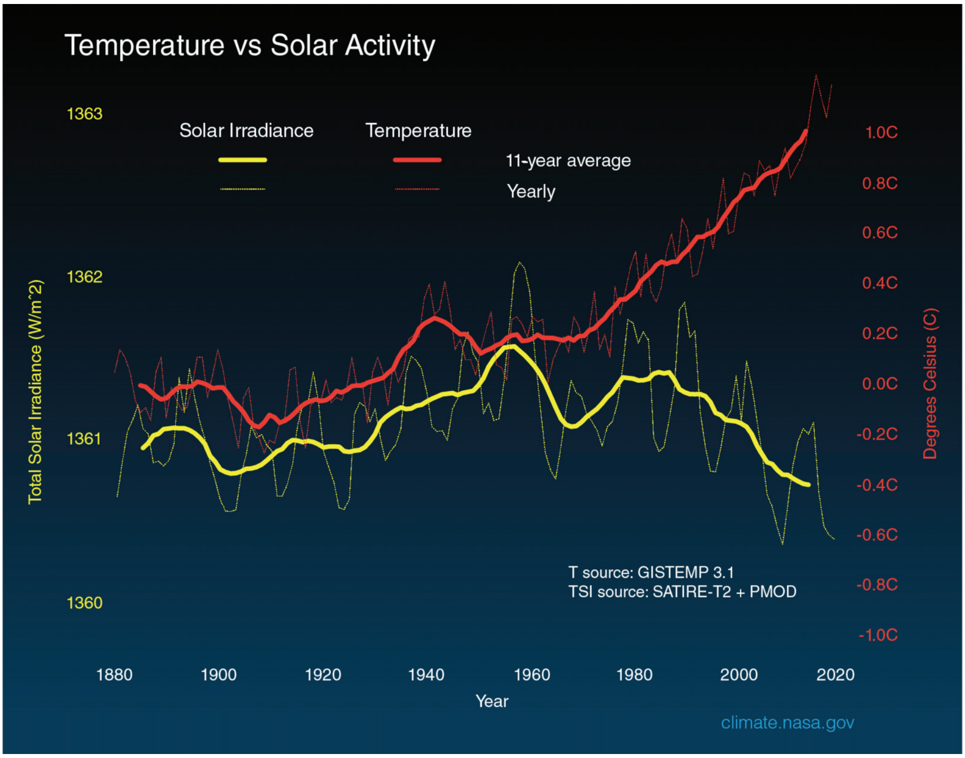


Color Plate 1: Black numbers indicate estimated amounts of carbon in Earth reservoirs in preindustrial times in units of petagrams (1015 grams), which is equivalent to billions of metric tons. Black numbers adjacent to arrows indicate movement of carbon among reservoirs in preindustrial times. Red numbers are carbon movements from human activities averaged for the years 2000–2009. Ciais, "Carbon and Other Biogeochemical Cycles," Figure 6.1, p. 471. Used with permission.

carbon dioxide sticks around in the atmosphere before it is taken up by the land and ocean sinks. The best way to comprehend residence time is to think about the amount of carbon dioxide that humans emit over the course of a year, mostly from burning fossil fuels. In 2019, that was 37 billion metric tons, or 37 gigatons.[29] What is going to happen to all this carbon, and how long will those processes take?

It is reasonable to think that since all carbon dioxide molecules are alike, they will all go into land and ocean sinks at the

29 The 37 Gt datum, and an enormous array of other statistics about the carbon cycle, are available from the Global Carbon Project, at https://www.globalcarbonproject.org.



Color Plate 3: Comparison of global surface temperature change with variation in the rate of solar radiation energy reaching Earth. The units of solar irradiance are given in watts per square meter of surface. Credit: NASA.

Volcanoes and hot springs also deliver a small amount of carbon dioxide from the deep underground into the atmosphere. The amounts are so small, however, that they are not included in Color Plate 2. If volcanoes did contribute significantly to atmospheric carbon dioxide, we would see regular increases in the ppm level after eruptions. No such spikes are observed in the Keeling curve or other data sets—they show only steady increases, with year-to-year variations from the photosynthesis and respiration cycle and other aspects of the land carbon sink.[7]

Changes in sunlight intensity can also alter the climate. For example, sunspots wax and wane over an 11–year cycle, and the presence of fewer sunspots is connected to a decrease in the amount of sunlight that reaches the Earth. Despite this regular variation, there has been little to no trend towards increased sunlight since

7 See Figure 4 in Chapter 1 and the discussion therein.

Box 2.2: Greenhouse Gas Potency

Some interesting science supports the concept of carbon dioxide equivalents. Just as incoming sunlight has components corresponding to all the colors of the spectrum, emitted Earthlight also features a spectrum of colors, but all invisible to the human eye. Within that Earthlight spectrum, each greenhouse gas only absorbs the outgoing light of specific colors, determined by how its atoms are bonded together to make the molecule. Methane and carbon dioxide are quite different gases, and so the Earthlight colors they absorb are distinct. Because there is much less methane than carbon dioxide in the atmosphere, a much smaller proportion of Earthlight radiation in methane's colors is absorbed. More of that Earthlight continues out into space.

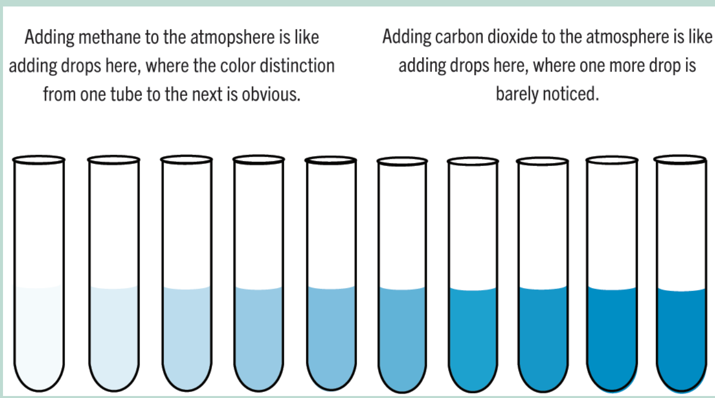
Here's the tricky part. The reason this makes methane a more potent greenhouse gas than carbon dioxide is that the amount of Earthlight of a particular color that can be absorbed by a greenhouse gas depends on how much of that gas is already there. The first ton of greenhouse gas emitted absorbs a lot of Earthlight, but each successive ton absorbs less and less, until just about all the Earthlight of that color has been absorbed. At that point the atmosphere would be fully saturated with that gas, and further emissions of it could not cause more warming. This can't solve climate change, though, because we are nowhere near saturation yet for any greenhouse gas.

Here is an analogy that may help. Imagine adding a drop of bright blue dye to a glass of water and letting it fully blend in. The color of the water changes from clear to pale blue (see the Figure). As you add additional drops, the blue shade gets deeper. However, the biggest distinction in color came with the first drop, since the water was originally clear. The second drop makes the pale blue darker, but you get less bang for your buck in the visual effect. And as you add more drops, the amount of additional blueness keeps getting harder to see. The extra intensity of color depends on how much color was already there before you added each successive drop. Emitting more methane to the atmosphere today is like adding drops to the glass when the color is still pale blue, while emitting more carbon dioxide is like adding drops when the color is already much darker. The warming impact from one more ton of carbon dioxide is much less than from an additional ton of methane, because carbon dioxide is a lot closer to saturating its preferred Earthlight colors.

(continued on next page)

Box 2.2 *(Continued)*

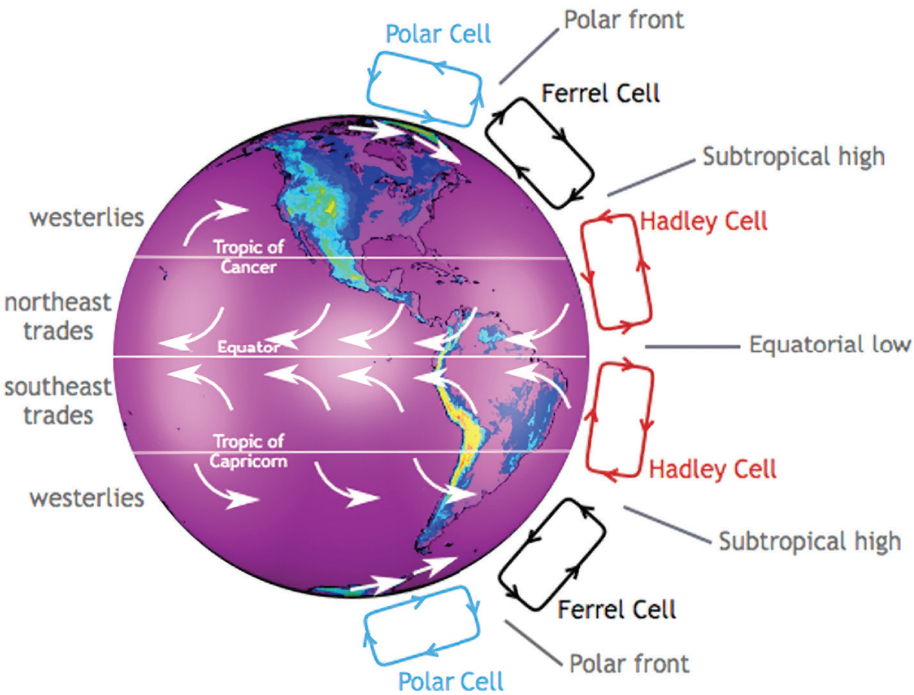
Since the residence time of methane is only nine years, it gets removed from the atmosphere quickly compared to most of the carbon dioxide. If we were to emit one ton each of methane and carbon dioxide today, and then wait 100 years to see the relative effects on trapping heat, we would find that the methane is 28 times more potent. But since the average residence time of methane is so short, as we get into the 100 years its contribution starts to really fall off. On a shorter time frame, which is much more relevant to policymaking, the CO2(e) for methane is higher—over 20 years, the CO2(e) is 86. We don't have 100 years to solve climate change; 20 years is much more like it. The fact that methane is 86 times more potent than carbon dioxide in this time frame elevates the importance of controlling its emissions as soon as possible.[50]



human contribution—and about 6–7 percent is from other natural sources: permafrost, the deep underground, lakes, oceans, and termites.[51] Except for the pipeline leaks, all emitted methane is a byproduct from the metabolism of an ancient class of

50 The nonprofit Greenhouse Gas Management Institute offers a very clear explanation of global warming potentials, at https://ghginstitute.org/2010/06/28/what-is-a-global-warming-potential/.

51 The data on methane is from the Global Carbon Project, M. Sausnois et al., "The Global Methane Budget 2000-2017," *Earth System Science Data*, no. 12 (2020): 1-63, DOI:10.5194/essd-12-1561-2020, https://www.globalcarbonproject.org/methanebudget/index.htm.



Color Plate 7: Depiction of the major atmospheric flow patterns that climate scientists seek to incorporate into climate models. Credit: NASA.

as can be done in many other areas of science. Certainly, limited experiments are useful; for example, the results of studying how the temperature of a gas mixture affects its ability to hold water are relevant and incorporated into climate models. There are also some "natural" experiments that can be looked at, like the 1992 Mount Pinatubo eruption that caused global cooling. But of course, there is no "control Earth" that would allow us to examine what would have happened had that eruption not occurred.[30] The only way to get insight into that is with a simulation.

Climate Models: Simple and Complex

To get a better feel for climate models, let's revisit the bare rock model of the Earth from Chapter 1. That model is so simple that it includes only a few equations that describe how the Sun's radiation affects the temperature of the Earth. And unsurprisingly, it yields

30 Paul N. Edwards, *A Vast Machine, Computer Models, Climate Data, and the Politics of Global Warming*, (Cambridge: MIT Press, 2010), 139-140.